Tomographic Image of the Proton from DVCS data

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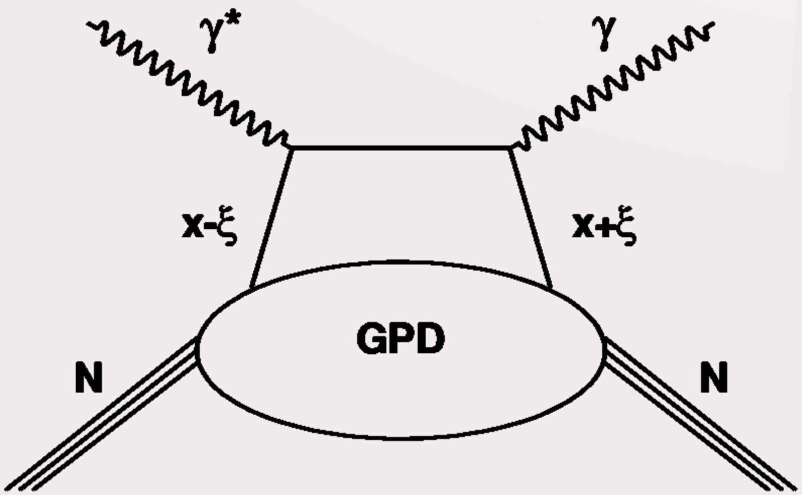
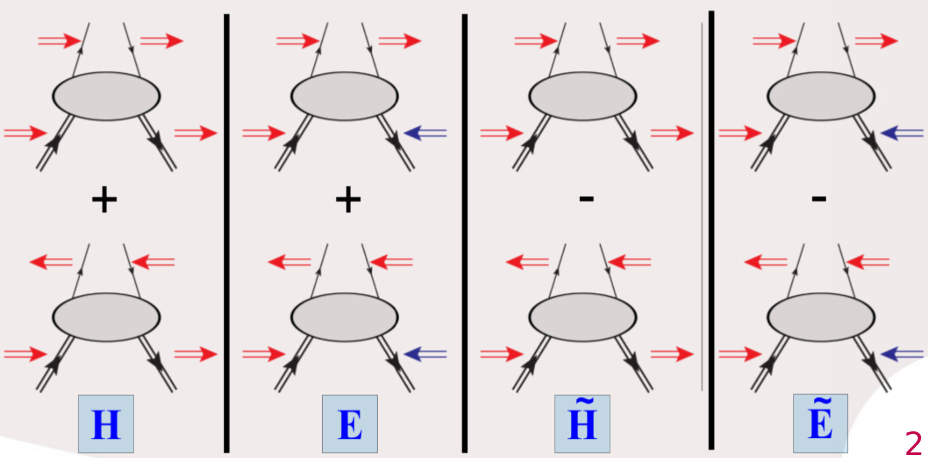
Generalized Parton Distributions

- **A Generalization of usual PDFs**
  - A description of the nucleon depending on 3 variables : x, ξ, t
  - Accessible through several exclusive processes (DV Compton scattering, DV Meson Production, Double DVCS…)
  - Spin-1/2 of the nucleon leads to 4 GPDs
- **Deep Virtual Compton Scattering (DVCS)**
  - Exclusive electroproduction of a photon
  - Using the factorization gives access to GPDs
  - However *x* is not observable in DVCS
  - Only Compton Form Factors (CFF) are accessible



$$F_{Re}(\xi,t) = \mathcal{P}\int_{-1}^{1} dx \left[\frac{1}{x-\xi} \mp \frac{1}{x+\xi}\right] F(x,\xi,t),$$

$$F_{Im}(\xi,t) = F(\xi,\xi,t) \mp F(-\xi,\xi,t).$$

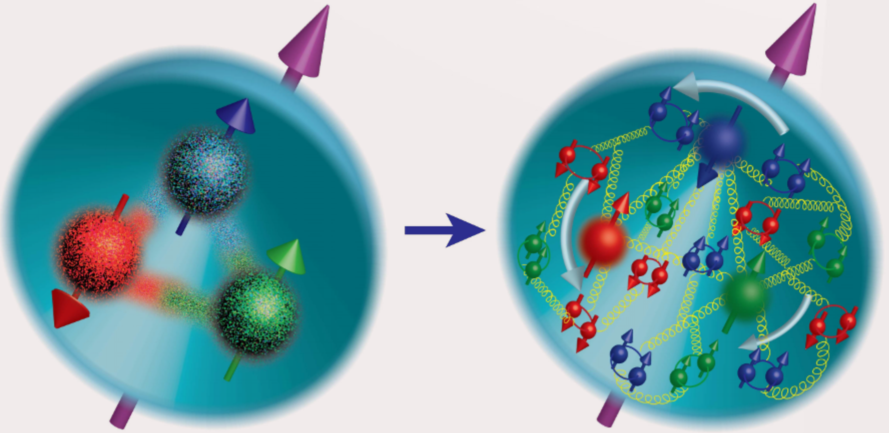


M. Guidal et al. Rept.Prog.Phys. 76 (2013) 066202

Generalized Parton Distributions

- **Many structure functions are used to understand the structure of the nucleon**
- **GPDs offer several advantages**
  - The link to PDFs is well established
  - Experimental access through DVCS

    A.V. Radyushkin Phys.Lett. B380 (1996) 417-425



- **GPDs give access to the proton spin through Ji sum rule**

$$J_{q,g} = \frac{1}{2}\int_{-1}^{+1} dx\; x[H_{q,g}(x,\xi,t=0) + E_{q,g}(x,\xi,t=0)]$$

X.D. Ji Phys.Rev.Lett. 78 (1997) 610-613

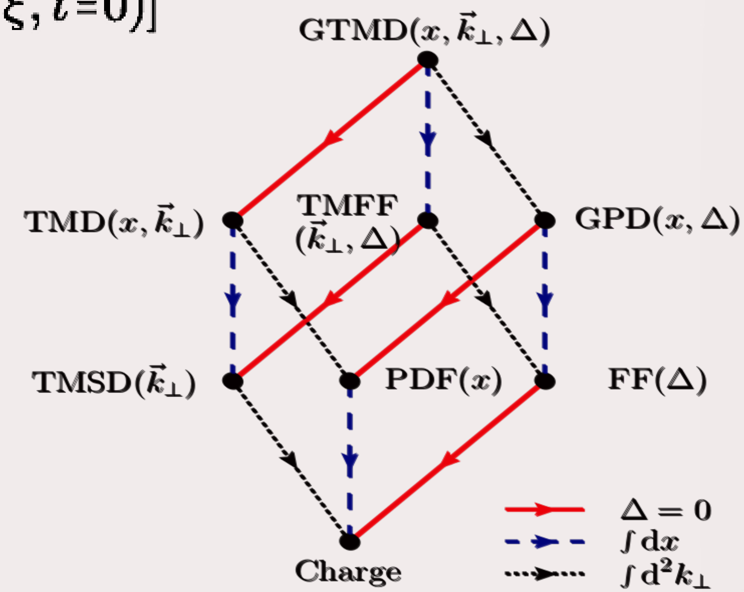
- **GPDs give a 3D image of the nucleon**

  M. Burkardt Phys.Rev. D62 (2000) 071503

- **And much more**
  - Pressure and shear forces in the D-term

    M. Polyakov Phys.Lett. B555 (2003) 57-62
  - Study of nuclei to understand the EMC effect and shadowing
    - With an access to non-nucleonic degrees of freedom in nuclei

R.D. & S. Scopetta Eur.Phys.J. A52 (2016) no.6, 159



C. Lorcé & B. Pasquini Phys.Rev. D84 (2011) 014015

Disentangling the CFFs

- **The 4 complex CFFs intervene as 8 free parameters in the calculation in various observables of DVCS**

  A. Belitsky et al. Nucl.Phys. B629 (2002) 323-392

  – We need many observables to extract all of them

  – Possible for one point using HERMES data

    - Includes transversely polarized target and beam charge asymmetries

  – JLab data however does not allow for a full extraction of that kind

    - Use the fact that the Im(H) dominate beam spin asymmetries

- **We have an underconstrained set of equations**

  – If we want to get to the 3D picture of the nucleon, we will need some tricks

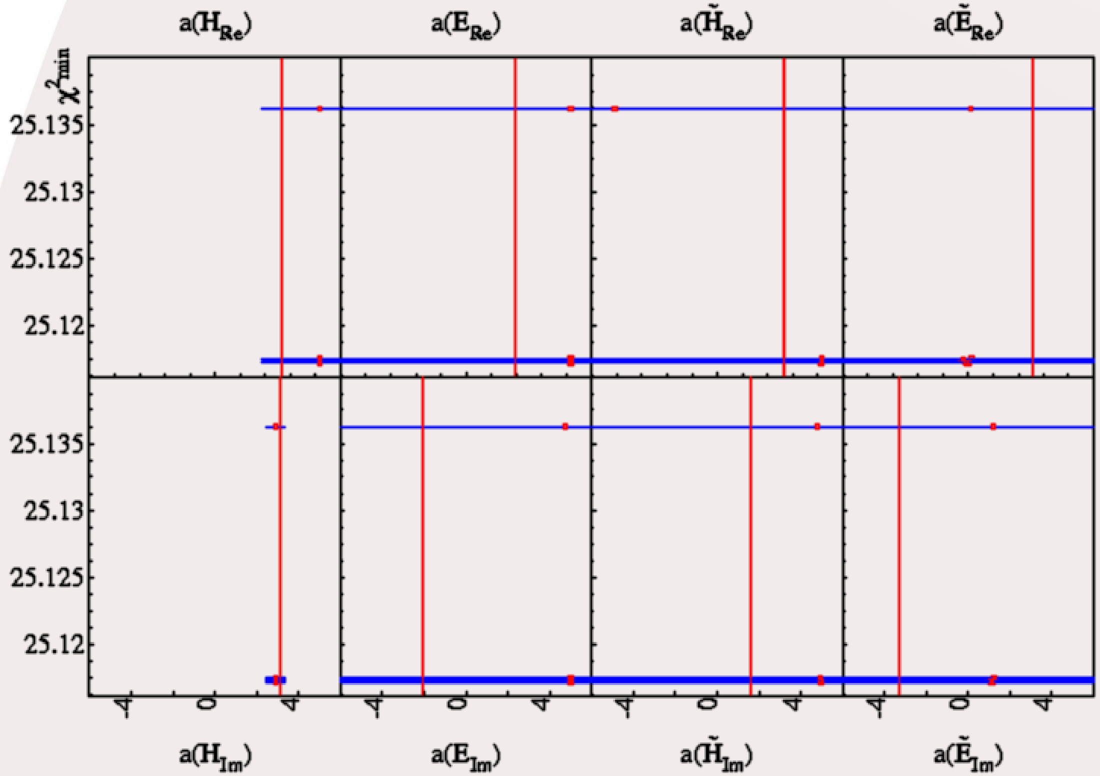
$$\Delta\sigma_{LU} \propto \sin\phi \;\; Im\{F_1\mathcal{H} + \xi(F_1+F_2)\tilde{\mathcal{H}} - kF_2\mathcal{E} + ...\}$$

$$\Delta\sigma_{UL} \propto \sin\phi \;\; Im\left\{F_1\tilde{\mathcal{H}} + \xi(F_1+F_2)\left(\tilde{\mathcal{H}} + \frac{x_B}{2}\mathcal{E}\right) - \xi kF_2\tilde{\mathcal{E}} + ...\right\}$$

$$\Delta\sigma_{LL} \propto (A + B\cos\phi) \;\; Re\left\{F_1\tilde{\mathcal{H}} + \xi(F_1+F_2)\left(\mathcal{H} + \frac{x_B}{2}\mathcal{E}\right) + ...\right\}$$

$$\Delta\sigma_{Ux} \propto \sin\phi \;\; Im\{k(F_2\mathcal{H} - F_1\mathcal{E}) + ...\}$$

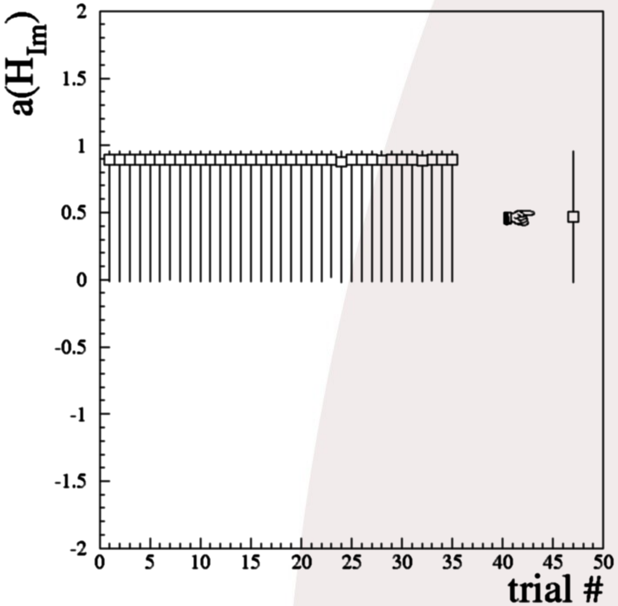
Tests with Pseudo Data

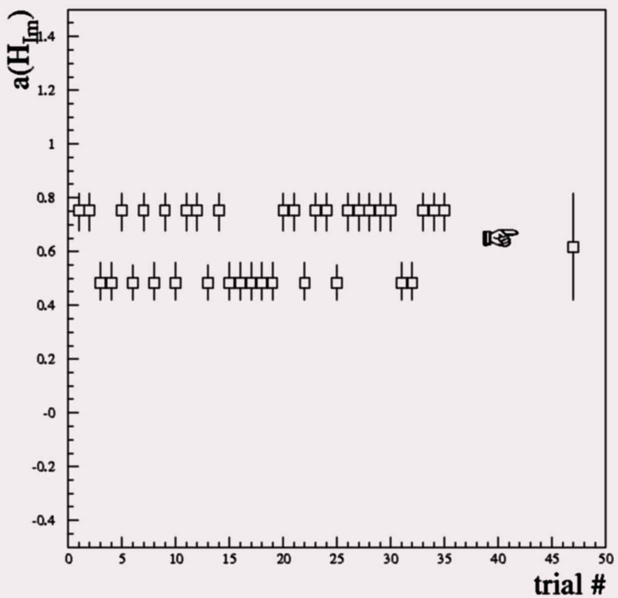


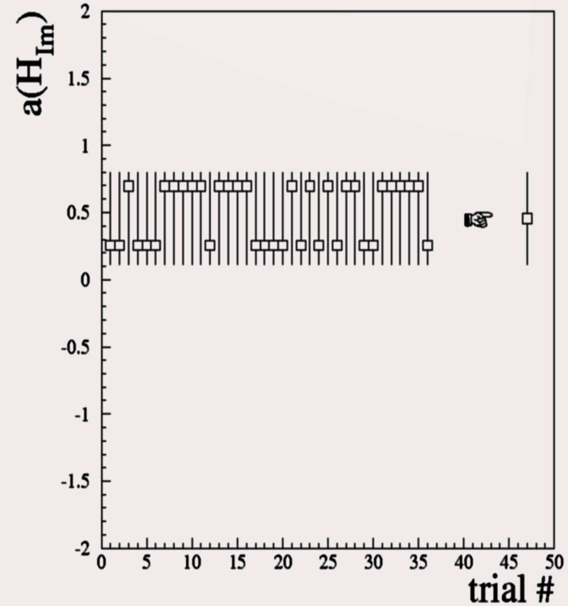
- **As expected the 8 parameter fit cannot converge without constraints**
  - Choice of educated limits for the local fit → ± 5 x VGG Model predictions
  - As expected H appears to be the only GPD constrained by CLAS data
- **Fit sometimes cannot find a single unique solution**
  - We ran many fits on pseudo data in order to test the stability of the fitting procedure

    → Whatever we use in the start, we recover H properly (within error bars) at the end

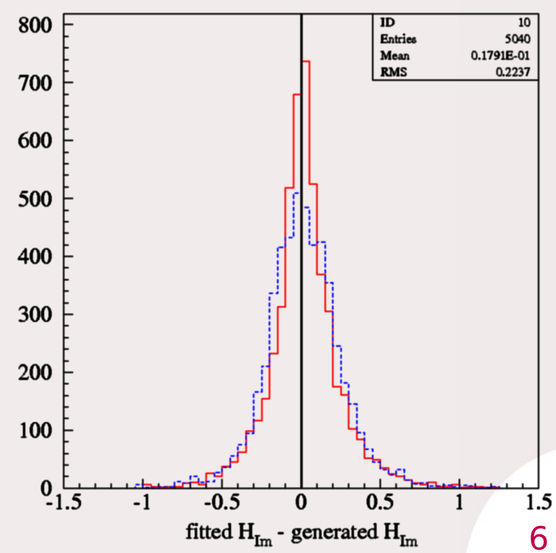
Using central values



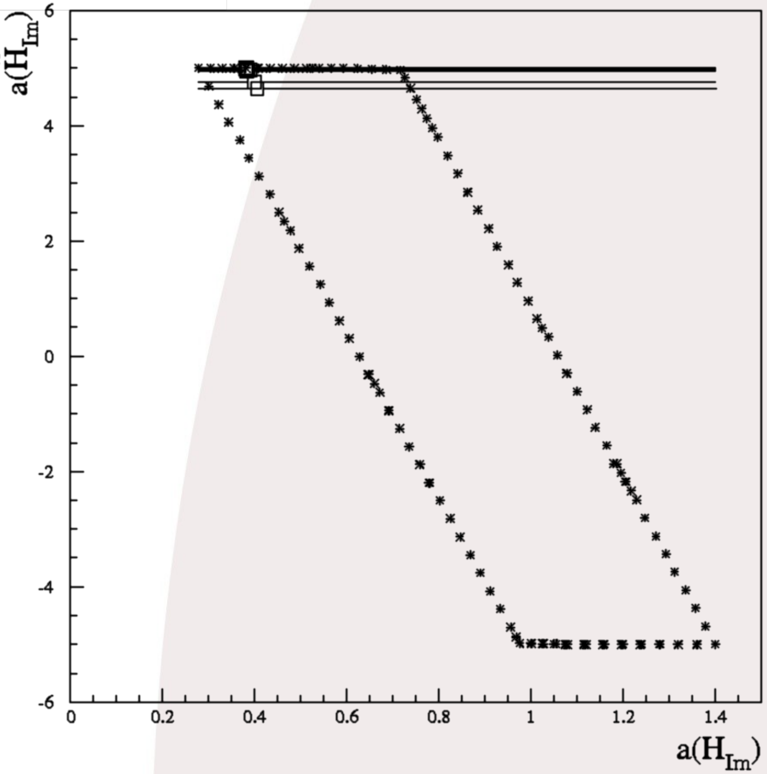


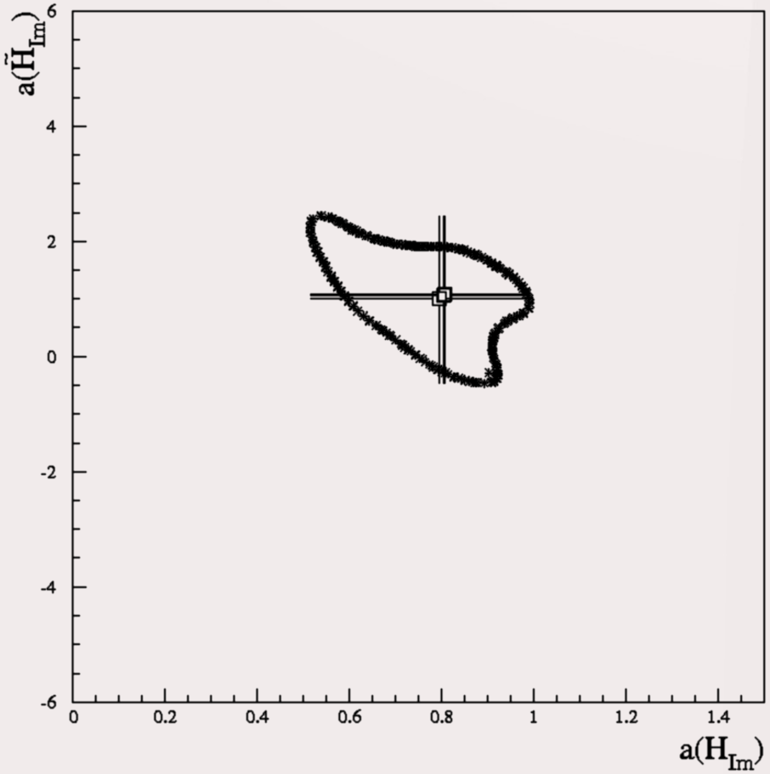


- **In some cases the fit gives problematic results**
  - Explored with many independent pseudo-data sets and fit starting points
  - Highly asymmetric error bars
    - Do not reflect properly the χ^2 profile
    - De to very flat χ^2 valley
  - Double solutions
    - Problematic for the coming global fit, which solution to use ?
- **We found that the central value of the error bars works best**
  - This is natural since subleading CFFs are in fact not significantly constrained and the minimum χ^2 in their range is most of the time not significant
  - This was confirmed by simulation



Importance of new observables





- **Adding target asymmetries constrains naturally the Im($\hat{H}$)**
  - Incidentally it also constrains Im(H)
- **However these data are not available for all kinematics**
  - More observables would be needed to constrain E and Ẽ
  - Transversely polarized target and charge asymmetries for example

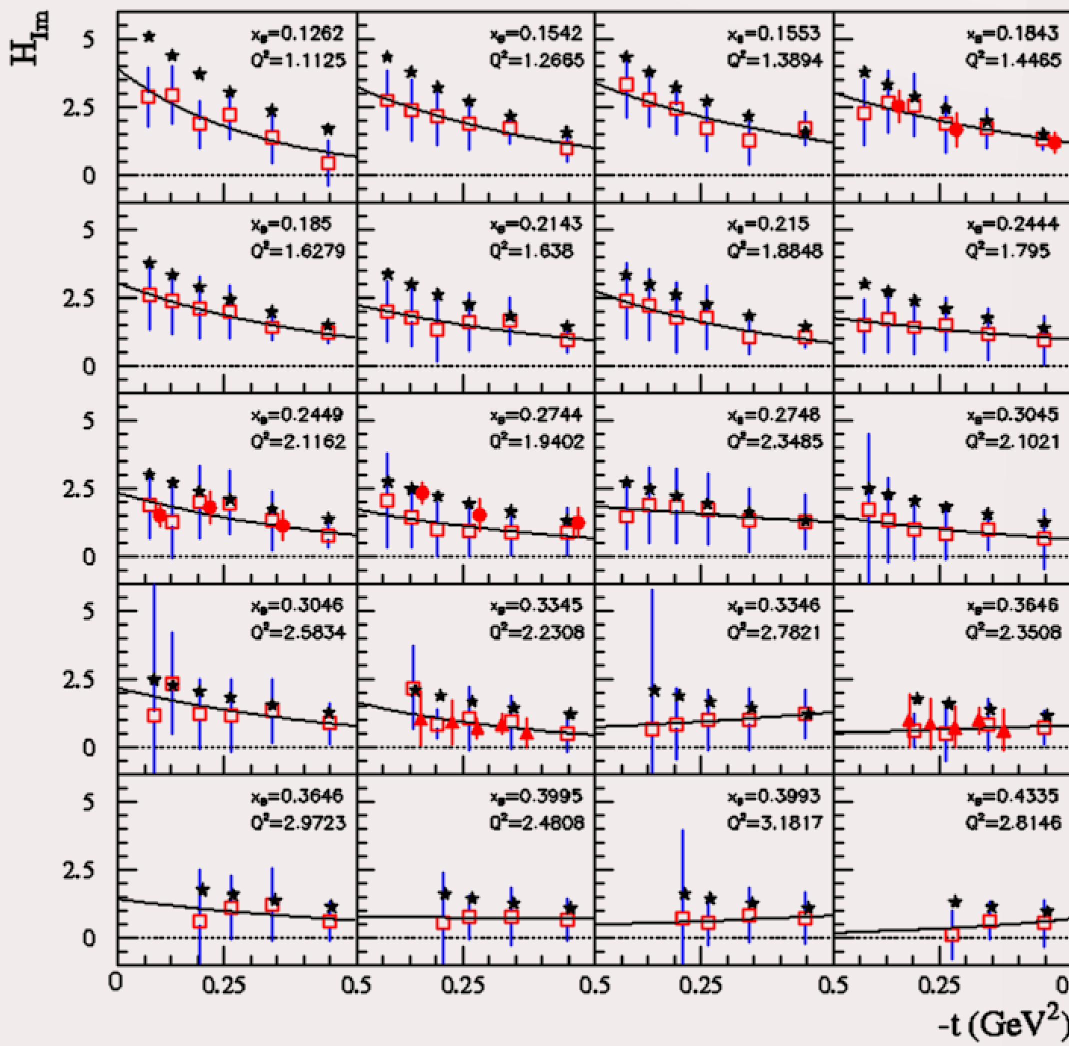
Extraction of Im(H)

- **Applying the local fit method for the JLab data**
  - Jlab Hall A (σ, Δσ)
  - CLAS (σ, Δσ, lTSA, DSA)

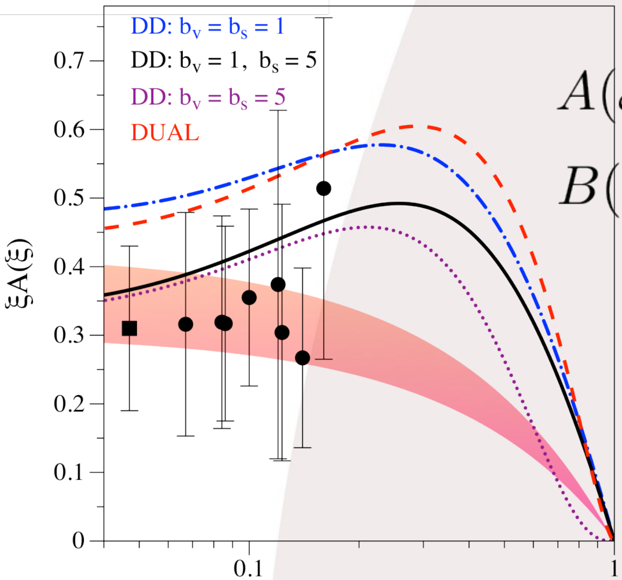
- **Gives enough coverage to explore the *t* and x_B (→ ξ) dependence**
  - Fitted with an exponential form

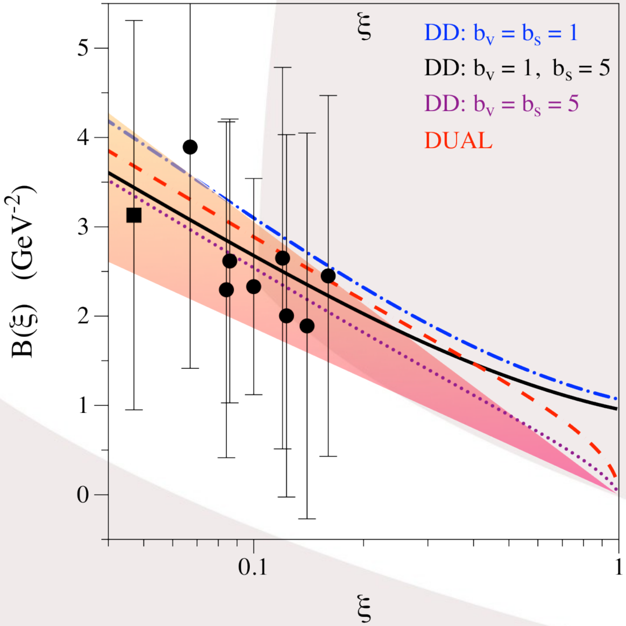
$$\mathcal{H}_{Im}(\xi,t) = A(\xi)e^{B(\xi)t}$$

- **Results are generally close to the VGG model**



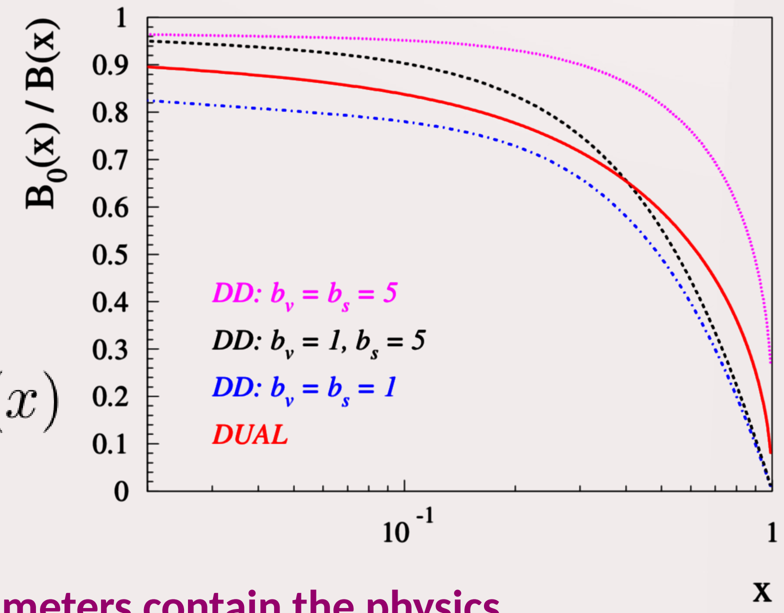
Amplitude and Slope





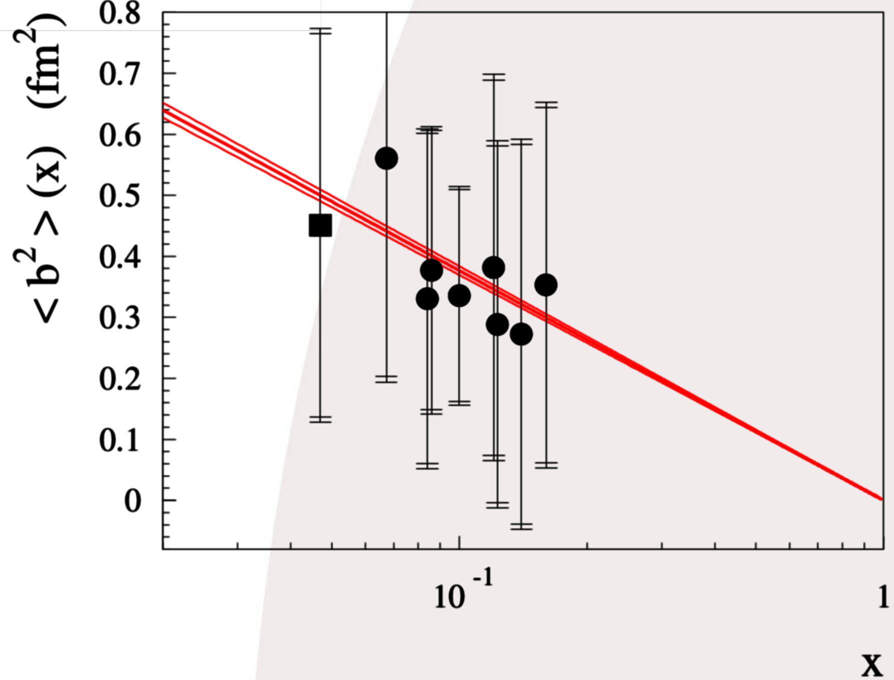
$$A(\xi) \ = \ a_A(1-\xi)/\xi$$
$$B(\xi) \ = \ a_B \ln(1/\xi)$$

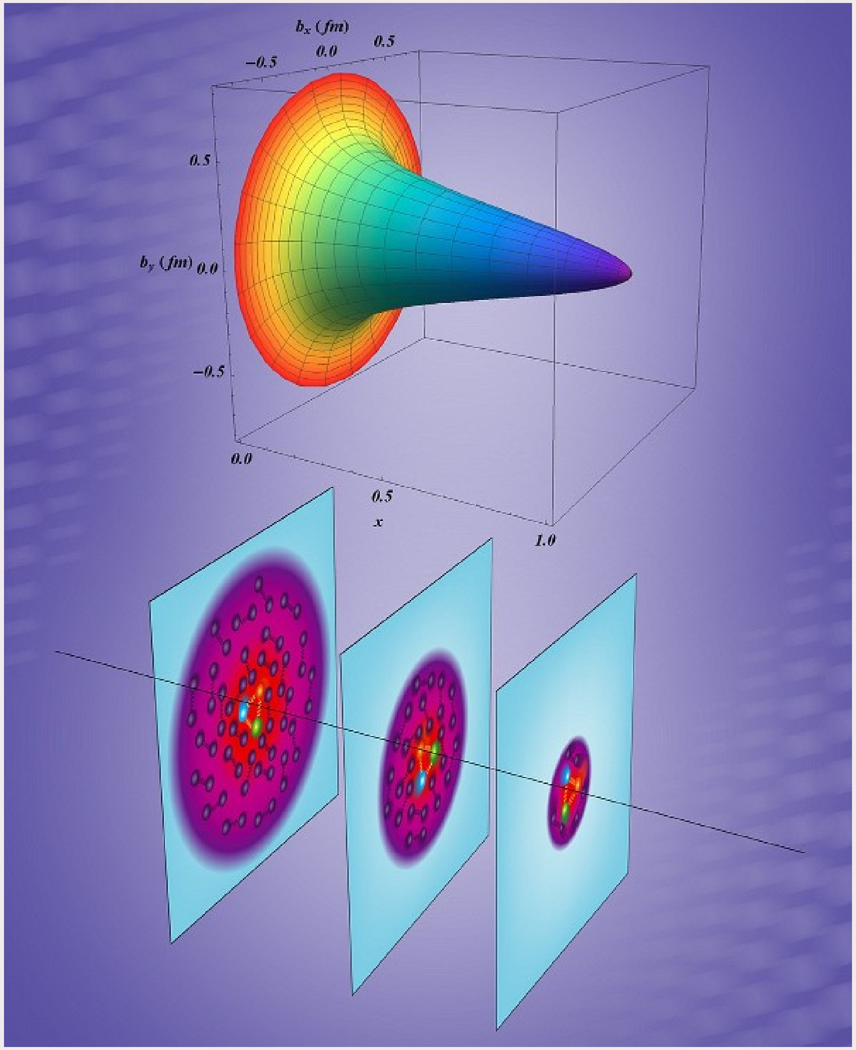
$$\langle b_\perp^2 \rangle^q(x) = 4B_0(x)$$



- **The A and B parameters contain the physics**
  - Linked to density and to transverse size
- **Fitted using educated guess**
  - Asymptotic behavior expectations similar to PDFs
  - In the future with larger amount of data, models can be tested at this level
- **The tomography of the nucleon**
  - Not directly accessible with DVCS, need a ξ dependent correction to go from the singlet to the non-singlet distribution
  - We note that at low *x* the correction is small and similarly described by several models

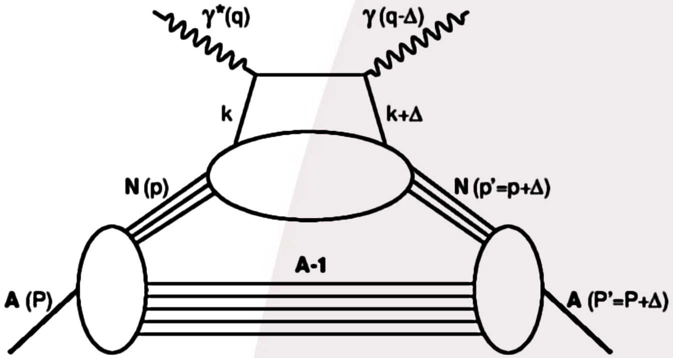
Results

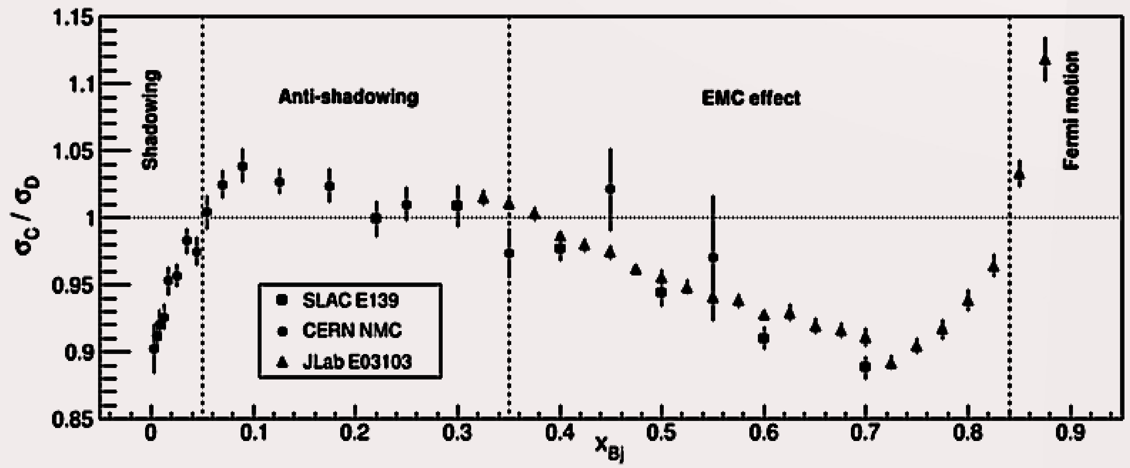




- **We obtain the tomography of the proton**
  - Mean square charge radius of the proton for slices of *x*
  - Error bars reflect the unknown CFFs
    - To flatten this distribution, one would need a non constrained CFF with very strong unexpected behavior

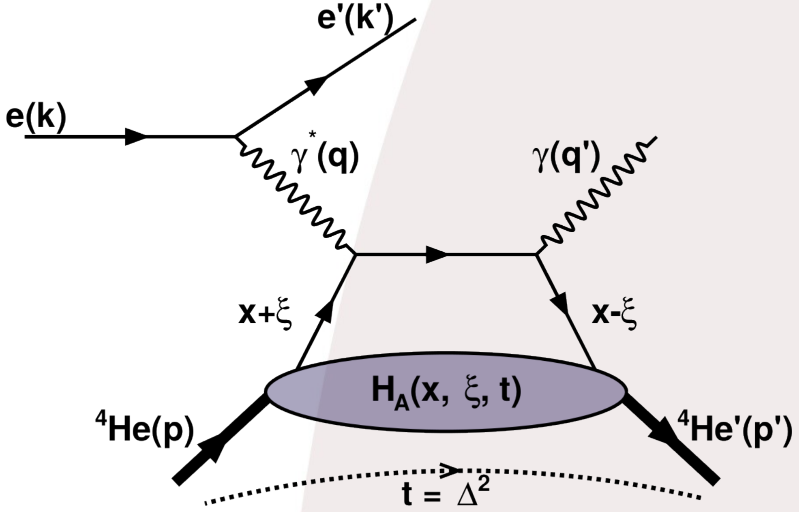
Nuclear GPDs



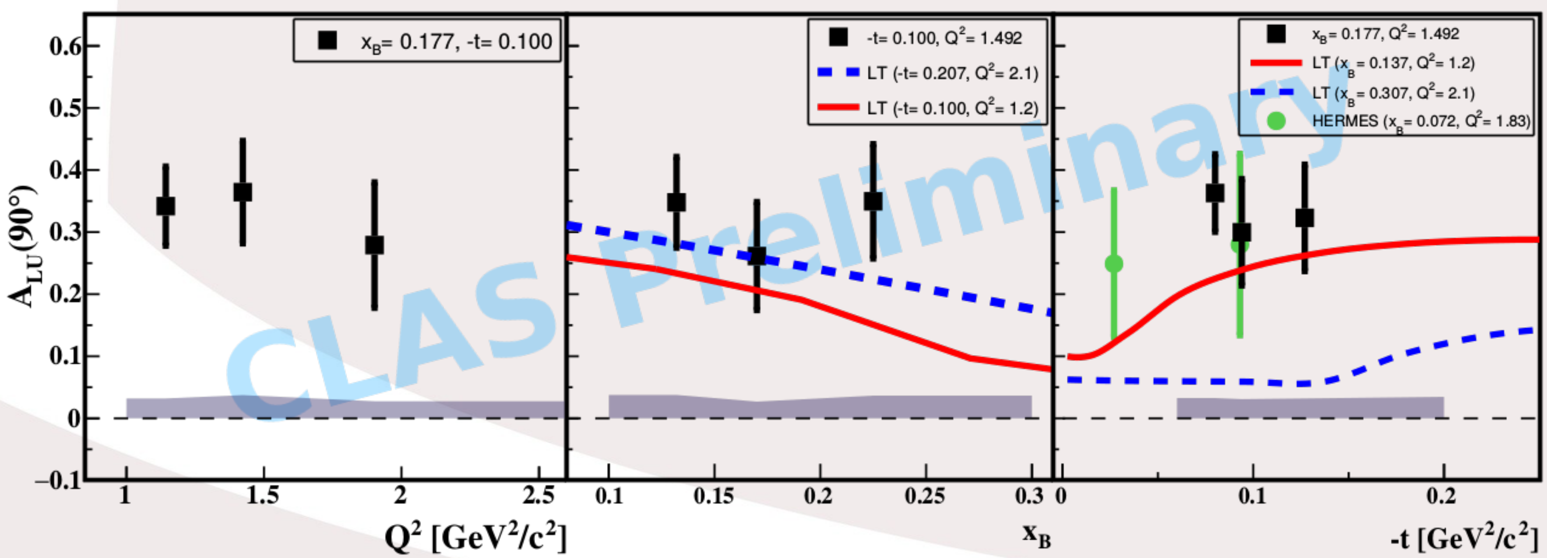


- **New view on nuclear effects**
  – GPDs offer a completely new point of view into this problem
- **Experimental access to completely new nuclear physics**
  – Non nucleonic degrees of freedom of the nuclei
  – Measure pressure and forces in the nuclei
  – Localize the EMC effect
  R.D. & S. Scopetta Eur.Phys.J. A52 (2016) no.6, 159
- **Allows to play with the spin**
  – Use of helium 4 for a simplified problem with only 1 GPD
  – Which can be extracted from DVCS beam asymmetries only
  – Use of helium 3 and deuterium to understand the neutron and more complex spin dynamics

DVCS on Nuclei



- **Already measured at Jlab (CLAS)**
  - Coherent DVCS is cleanly measurable
    - Collider kinematics would make it much easier !
  - Asymmetries are much larger than for the proton
    - As expected from theory
- **The start of a new domain for GPD studies**
  - Already many studies on the theory side
    - In both valence and shadowing regions



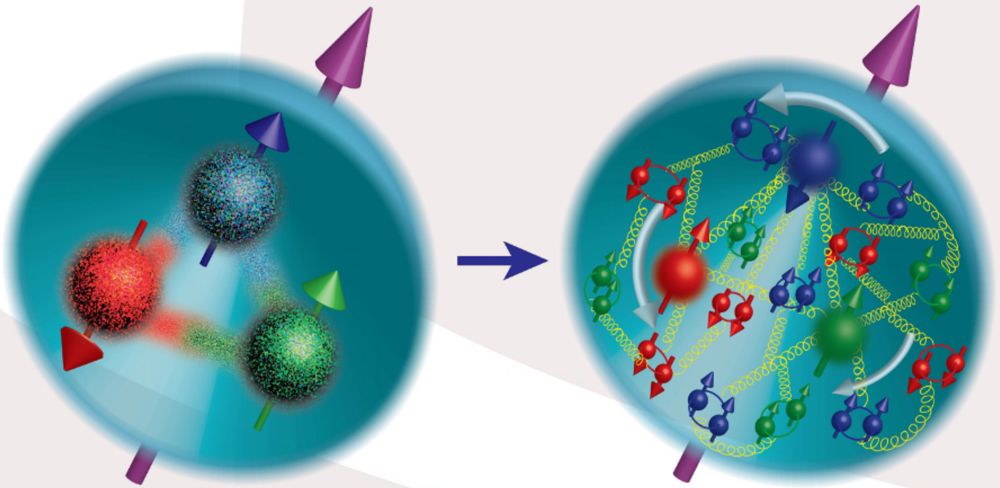
Future at JLab 12

- **A very wide approved program**
  - Proton DVCS (σ, Δσ) in Hall A (running already) and CLAS12
    - Also with longitudinally polarized target
    - Q^2 scan in Hall C, beam energy scan in CLAS12
  - Neutron DVCS (σ, Δσ) in CLAS12
    - Also with longitudinally polarized target
  - Transversely polarized target measurement (HD Ice target)
  - And many other projects proposed

- **JLab will provide a very large data set in the valence region**
  - We should try to equal this for the sea region at EIC

Summary

- **We make the tomography of the nucleon**
  - Errors can be reduced by including more observables
    - Cross-sections, beam spin asymmetries, target asymmetries..
    - Transverse target, positron beam



- **We show for the first time that the proton is smaller at higher *x***
  - with minimum model input
- **What does it says for EIC :**
  - We need high luminosity
  - High polarization of both beams
- **What to do to go beyond**
  - Measure other processes
    - Double DVCS, Time-like CS…
    - Charge asymmetries, transverse polarized target